MAYA - A PC BASED ENVIRONMENT FOR ANALYZING WILDLIFE HABITAT

FINAL REPORT FOR COA #INT-87215-COA with
SYSTEMS FOR ENVIRONMENTAL MANAGEMENT
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Introduction

MAYA is a collection of software tools designed to help wildlife researchers evaluate and analyze wildlife habitat. MAYA is itself not a "GIS" so much as an environment within which GIS related tasks may be performed. The software was developed through a cooperative research agreement between the U.S. Forest Service Intermountain Research Station, and Systems For Environmental Management in Missoula, Montana. One of the more difficult tasks inherent in this project was finding a name to label the various diskettes and binders that seemed to proliferate as the project took shape: thus, MAYA was born. The term is not an acronym concealing an obscure four word title -- it is taken from the buddhist teachings regarding the illusion of the world's permanence, an apropos term in light of the project's early goals.

Philosophy and Goals

MAYA is about tools. Tools are used to build new things and to maintain old things. Good tools in the hands of able craftsmen blur the distinction between the idea, and the building material used to express the idea. Data is a building material of science, and hypothesis, an idea of science. Good software tools can help the scientist fuse ideas and data into understanding. Bad software tools are most noticeable for the way they burden the scientist with hyperbolic detail while masking important relationships in the data.

A great deal of software for conducting wildlife research has been developed throughout these past few decades, perhaps most visibly in these last five years. This evolution has occurred at the approximate intersection of two emergent trends: a) a general growth, sophistication, and legitimization of quantitative modelling in the life sciences, and, b) an explosive growth in the availability and access to digital computer technology. Wildlife biologists, whether involved in management or research, are very aware that in today's litigious political climate, both a qualitative and robust quantitative perspective are often required to substantiate the kind of ecological balances that have historically been considered "just common sense".

Many of the early biology-software development efforts arose from investigations into such areas as mathematical ecology. population biology. (Metzgar 1979) home range analysis (Anderson 1982, Dixon and Chapman 1980, and Stuwe et al 1983), fire ecology. and multivariate analysis of plant communities (Gauch 1982). A subtle side effect brought about by the increasing access to sophisticated computer technology was that the biologist's expectations about the class of problems able to be solved, and the resolution these problems might be solved at, grew apace (or exceeded) the development of the technology itself. The advent of powerful desk top computers and "workstations" has further personalized the technology. bringing incredible computing power to individuals previously shielded from most of the vagaries of managing a computer by the MIS administrator of a time share mainframe account.

Enter the current wave of GIS technology. For biologists more or less accustomed to working with computers in predominantly one dimension (time), we now add the dimension of space, and with that, another healthy increase in our expectations. Understanding and solving spatially oriented problems, however, requires additional skills, in areas such as cartography. and analytic geometry at the least. But the resources required to acquire a facility in two (and three) dimensional problem solving come at even greater expense than those required to solve problems in one dimension.

The implicit promise of computer technology has always been that previously unassailable problems would now be made tractable by dint of more powerful hardware, and one presumes, more intelligent software. Yet the ways in which the software element of this equation has lagged behind the hardware has made the realization of this promise seem to recede even as we approach it. This is due in part to the non-linear increases in complexity inherent in the new hardware and software, and to the fact that

the more specialized we become in our fields (e.g. wildlife biology), the less resources we can generally devote to mastery of the tool.

The result, relevant to more than a few biology related software projects (and now, GIS applications) has translated to an imbalance between the elegance of the underlying theory itself and the implementation of the theory (e.g. the software executing the ideas). Simply put, many end-users of complex computer technology have neither the predisposition, motivation (or budgets) to master it at the level of their expectations. This juxtaposition is compounded by the fact that, however well engineered operating system software for workstations (such as MS-DOS 3.x,4.x and UNIX Rel 5.x) may be from the inside, from the user's point of view they are still unintuitive at best. Possible exceptions include Apple's MacIntosh ("Finder" and "Multifinder") and some aspects of the new OS/2 Presentation Manager.

Some contemporary users tend to blame the technology itself, for not being more "friendly". Someday it will probably be more friendly -- but only after we collectively learn enough about the Frankenstein we've already created to teach it to act more friendly. Meanwhile, we should resist the overselling blitz and scale our expectations closer to the present reality. The irony is that waiting for this catch-up to occur demands a kind of patience somewhat alien to users of increasingly fast hardware.

Suppose for a moment we imagine software programs as consisting of only two elements: an "interface", and an "engine". The interface, of course, is the aspect of the system the user experiences visually (the screens), and tactilly (the keyboard, mouse etc). The "engine" is experienced primarily only through the lens of the interface. To over-generalize, biologists and ecologists have often been responsible for mating respectably elegant "engines" with pleistocene "interfaces". On the other hand, leave the same task to a software engineer (and/or database manager) devoid of the biologists insight, and you may end up with a robust, pleasing "interface" attached to an "engine" misfiring on all cylinders. The contribution of each discipline alone provides a necessary but insufficient perspective to produce an ideal program; a system incorporating both perspectives, however, seems more likely to approach the ideal.

Much biologically related software is developed and used by the same individuals. A distinction worth emphasizing here is that the skills and perspective of the developer of such software need not be the same skills and perspective required of the user of that software. The fact that, within many organizations, the "developer" and "user" role are often blurred into one person continues to obfuscate this distinction, leading to some of the situations discussed above.

There are no easy answers to these dilemmas. Incorporation of GIS methods into traditional wildlife biology seems to demand a higher level of interdisciplinary cooperation then ever. Although MAYA is neither alone nor exemplary in this effort, it represents an effort to recognize the symbiotic contribution of both the biological and computer science perspectives. MAYA is designed with the following general goals and assumptions in mind:

- Usable By Non-Experts — Wildlife researchers should not have to be computer experts or programmers to enjoy the benefits of modern wildlife analysis methods. They should, however, understand the concepts on a theoretical level.
- Transparent Operation — Software tools should operate as transparently as possible in the work environment, presenting the user with a robust, consistent, and unobtrusive interface between the research data and the tools used to manipulate that data.
- Highly Integrated — Analysis software should make it possible to integrate the tools that are used together (e.g. vector and raster GIS, statistical analysis software, graphics software etc) as seamlessly as possible.
- Scaled Support — Analysis software should attempt to scale its user support (e.g. method of accessing programs, help, etc) to match the needs of an evolving user, rather than to assume a user with static knowledge and experience.

Data Models Used Within MAYA

Both tabular and spatial data objects are used within MAYA. Tabular data sets exist in MAYA as orthogonal database tables in the common dBASE III+ /FoxBASE+ format. Spatial data objects exist as one of two types of thematic map coverages; vector, or raster. The definition of coverage is borrowed from the PC ARC/INFO system:

> "A coverage is a ...homogenous class of data within a map. In a coverage, map features are stored as simple points, lines, or polygons. Thematic descriptors, such as feature name, symbol, classification...are stored in feature attribute tables..." (ESRI 1987).

When map features are stored in vector form, they exist as points in continuous (or analog) space, whereas map features stored in raster form exist as regular shaped cells each possessing a parity (or attribute) value within a finite grid (or discrete) space (Monmonier 1982). The vector and raster form each have their advantages and disadvantages. The vector form is advantageous when we are interested in examining polygonal patches or regions, for example, in obtaining the perimeter or area of closed figures (Campbell 1987). Map features displayed in vector form are generally more aesthetic as well, since they more closely approximate the actual spatial characteristics of the features.

The raster form offers advantages for certain classes of proximity search and multi-layer map algebra (Berry 1988), and for interfacing with remote sensing data, (Campbell 1987). Thematic maps in raster form are particularly useful for constructing cartography products representing statistical surfaces, where cell parity values are the complex product of various functions involving adjacency relationships (Robinson et al 1984).

The current implementation of MAYA stores raster maps in the FoxBASE+ database tables. Database tables in dBASE III+ and FoxBASE+ format store data in direct access binary files, but actually store the ASCII representation of the data, regardless of its data type. Thus, an integer value that would normally require only two bytes if stored as a signed binary bit pattern may require up to seven bytes if stored in a database record formatted for a single numeric variable of width 5, with a leading space for sign and delete byte bringing the total to 7 bytes/integer).

While storing raster grid cell data in this format is considerably less efficient than storage in straight binary files, it does provide for a structural consistency with the other database tables MAYA requires, and offers direct access to the parity value of any grid cell. MAYA does however store inactive maps in a compressed form, often reducing the storage space required by 70-85 percent.

Wildlife Habitat Analysis Within MAYA

Wildlife habitat research is currently on the threshold of a techniques revolution. In the next few years, we foresee changes in experimental designs, in logic, and in analytic technique; with results that could quite possibly change the existing philosophy of habitat management for wildlife. We predict significant increases in our understanding of habitat selection and utilization by free ranging wild animals, and for some wildlife species we expect greater precision in quantification of habitat values. Two unrelated concurrent developments are leading toward coincidence in application of habitat values to wildlife habitat research.

The first development has been the increasing longevity of radio transmitters on free ranging wild animals. Only a few years ago, transmitter failure within 90 days was virtually predictable. Today. scientists working with elk and grizzly bears are reporting transmitter failure after 4 and 5 years. At the same time, the ability to accurately locate animals in rugged terrain and heavy cover has substantially improved.

A second, simultaneous development has been the increasing speed and utility of GIS capabilities on both mainframe computers and, more importantly. on increasingly powerful personal computers. By itself, GIS technology will not provide appropriate analysis of habitats near animal locations, but GIS will make it possible to examine large numbers of locations in various ways in a short time.

The essence of habitat evaluation for wildlife is that the combinations are more important than the parts. Even the least complex of questions requires examination of all available components. One of the most common study designs in habitat research involves comparison of habitats at recorded locations with habitats at random points (Marcum and Loftsgaarden 1980). The resulting information is interpreted to indicate preference or avoidance of sampled habitat niches. A more specific and immediate research design involves detection of the extent to which land management actions are correlated with habitat preference and avoidance. Distance to the nearest road, for example, has been shown to reduce habitat effectiveness for both elk (Lyon 1983) and grizzly bears (McLellan 1989).

The most exciting research designs, however, are those testing multiple component relationships within habitats. If wildlife habitat models are to function with accuracy. they must be built on data derived from studies of seasonal habitat selection, specific daily stress, physiological or behavioral requirements, and responses of animals to identified stress conditions (Lyon 1985, Servheen and Lyon 1989).

MAYA is a programmed environment in which the kinds of information needed for these analyses are easily and quickly collected. The four specific types of analyses offered within MAYA include a) Identification of polygon attributes beneath points, b) calculation of minimum point to edge distances, c) generation of polygon attribute frequencies within sample frames, and d) Roving window simulation analysis. Each of these are described in detail later.

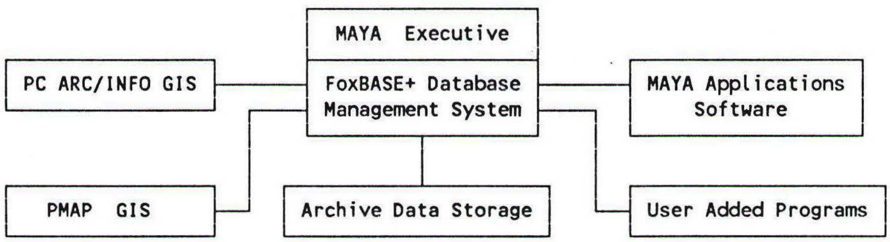
MAYA - The System

Computer Resources Required To Run MAYA

MAYA is designed to run on common microcomputers running under the MS-DOS version 3.xx (or higher) family of operating systems. It nominally requires a microcomputer with an 80286 CPU running at 12mhz or faster, at least 640K of RAM, a hard disk of at least 40MG capacity. and a EGA color graphics subsystem. A more practical configuration would include a 70 Megabyte or larger hard disk with at least a 28ms average access time, an Intel 80x87 NDP math coprocessor, and from 1 to 4 Megabytes of RAM. Disk caching, whether executed in hardware or software,is highly recommended due to the file intensive nature of MAYA.

Organization

MAYA comprises a menu driven executive which surrounds and controls various subsystem tools. The main system programs include ESRI's PC ARC/INFO vector GIS, FoxBASE+ by Fox Software, the PMAP Raster GIS, by Spatial Information Systems, and four custom raster analysis modules (described in detail later). Another facility allows the user to define a list of his/her local programs for execution within MAYA. A more formal interface to the IDRISI Raster GIS (Eastman 1987), available from Clark University. is under consideration for a future revision. Appendix A illustrates a complete process flow diagram for MAYA. The diagram below illustrates central role of the database manager to MAYA's other components:



MAYA's Two Faces: Ad-Hoc And Menu-Driven

MAYA provides an entry point to tools offering two different approaches to wildlife research: an ad-hoc view, and a more structured view through the use of custom analysis modules. These two approaches ideally work in a complementary manner; assuming that research objectives and an initial hypothesis exist, the ad-hoc approach can provide an unstructured, exploratory environment within which more specific questions may be addressed using the custom analysis functions.

In the menu driven context, the executive program (MAYA.FOX) shields the user from many of the intricacies of the subordinate tools. The menu driven "outer shell" serves as an intelligent control center from which almost all other MAYA facilities can be reached. The MAYA executive provides many features to help streamline repetitive tasks.

Using MAYA's tools in an ad-hoc context assumes a greater familiarity and experience with the intricacies of the various programs. Experienced users interested in directly performing a given task should not necessarily be forced to traverse a series of menus when they know what they want to do, and how to do it more directly; MAYA lets these users access the subsystem level tools directly.

MAYA's Ad-Hoc Tools - An Overview

PC ARC/INFO GIS

There are few limitations in the way MAYA can be used for ad-hoc explorations of spatial wildlife habitat relationships. The ambitious user willing to rigorously investigate the PC ARC/INFO software and extensive documentation will find a rich set of interactive capabilities for creating, editing, and analyzing vector based coverages. Although PC ARC/INFO does not currently offer any raster based analysis facilities, vector coverages in ARC/INFO can be easily rasterized, up to a maximum resolution of 5000 rows by 5000 columns, and brought into other environments, such as PMAP or IDRISI, database management tables, or electronic spreadsheets for further manipulation and graphical display.

The GIS modules supplied by ESRI used within MAYA are:

- PC ARC/INFO Starter Kit
- Grid Conversion Module
- Overlay Module
- ARC/EDIT Module
- ARC/PLOT Module

At this time, the Network Module available with PC ARC/INFO is not employed within MAYA. The Network module has the important potential to serve as an analysis engine for questions regarding wildlife travel paths, habitat use patterns influenced by forest road networks, and related questions. MAYA was developed using PC ARC/INFO Version 3.2.1; features in future versions such as V. 3.3 and V. 3.5 may result in significant improvements in the system.

FoxBASE+ DBMS

The FoxBASE+, Version 2.10 DBMS program is used as the gateway to all MAYA system and data tables. Used interactively. this software includes a menu driven command mode, called Fox Central, as well as offering the standard "dot prompt" command mode. FoxBASE+ uses the same file format as dBASE III+, dBASE IV, dBXL and CLIPPER. Using FoxBASE+, any MAYA database table can be interrogated, and resulting list style and/or formatted reports may be directed to the screen, printer, and/or a disk file. FoxBASE+ offers fairly good database performance level, considering that all numeric data it maintains is stored in an ASCII representation rather than binary. Especially helpful to the new user is the FoxBASE+ help system, a context sensitive help system assessable at any time.

In addition to excellent dBASE III+ compatibility. the FoxBASE+ system includes several valuable add-on tools, including a program design/generator tool, a database program documenter, and a pseudo-compiler. FoxBASE+ includes facilities for importing a variety of ASCII format data files into its database table format, including text files delimited (by blank, comma, or other symbol), or system data format (where data fields occurs in regular fixed column positions).

PMAP Raster GIS

The PMAP GIS for microcomputers, by Spatial Information Systems, offers a wide variety of raster based GIS analysis functions, and may operate on coverages originating in PC ARC/INFO as vector coverages after they have been rasterized and imported into PMAP. Very sophisticated map algebra and digital cartography analysis functions may be performed within PMAP, although these are limited to two maps at one time. PMAP is currently in version 2.5, with version 3.0 to be released sometime during the 3rd quarter, 1989.

PMAP, for Professional Map Analysis Package, is a descendant of MAP, a more comprehensive digital cartography analysis program from YALE University initially developed for academic training purposes. PMAP capabilities may be grouped into seven functional groups :

Functional Group	*Example Functions*
Data Encoding	GRID, MAP, POINT, STRIP, TRACE
Storage and Control	COPY, DEFINE, INFORM, SCALE
Output	CROSSTABS, DISPLAY, PRINT, SURVEY
Reclassify	CLUMP, RENUMBER, SIZE, SLICE
Overlay	AVERAGE, COMPUTE, COMPOSITE, COVER, INTERSECT
Distance	DRAIN, RADIATE, SPAN, SPREAD, STREAM
Neighbors	INTERPOLATE, ORIENT, PROFILE, SCAN, SLOPE

PMAP is a command driven program whose conceptually robust capabilities are somewhat offset by a quirky user interface. The command syntax is often inconsistent with the on-line help, fairly inflexible and demands a great deal of new users in particular, despite the attempt at a context sensitive help subsystem. The most serious limitations involve the maximum resolution of maps that may be manipulated using PMAP; version 2.51 limits maps to approximately 180 by 180 cells. The program is evolving however, and some of these shortcomings may be corrected with changes in the version(s) yet to be released. Despite its current flaws, PMAP remains one of the few comprehensive raster cartography analysis programs available for microcomputers. Although we were unable to examine the IDRISI raster GIS, V. 3.0 (from Clark University) in depth in time for this paper, it appears to offer capabilities at least as comprehensive as PMAP.

At this time, the interface between MAYA and PMAP is not well developed. Increased resolution capabilities in version 3.0, which we have not yet received, has deterred more than an informal relationship between PMAP and MAYA.

MAYA's Menu Driven Executive - An Overview

MAYA's other face, the menu driven executive, provides access to a comprehensive data management environment as well as to the four raster analysis functions. The core software components within MAYA consist of a menu driven "front end" written in the FoxBASE+ database language, and a collection of analysis and data support modules written in the "C" language.

MAYA's menu system runs under the FoxBASE+ database manager (or FoxBASE+ runtime), which leaves relatively little RAM available for running large subordinate programs as child processes. For example, the PC ARC/INFO program ARC/EDIT requires close to 500K of free memory to execute. To execute these large programs, MAYA stores its current menu and logic state, and entirely swaps itself out of memory to make room for the child process. After the child process is complete, MAYA automatically reloads itself and restores its logic state.

MAYA's Heart - The Data Dictionary

MAYA employs a database table driven architecture. This distinguishes MAYA from most other microcomputer GIS environments, and offers several important benefits. The most important of these is that many types of data can be stored in a consistent, well understood format accessible from virtually all facets of the system. A single set of robust DBMS facilities, including the FoxBASE+ database application language, report generation, automated structure documentation and index generation, all apply equally to internal system tables as well as user-maintained data tables. All analysis engine modules written in "C" speak the same lingua franca, simplifying interprocess task communication.

Data Dictionary System IDs

The data dictionary maintains state information on all critical data objects known to MAYA. The term data object is used here, rather than file, because in some cases data objects are collections of files that are referenced as a single entry (object) within the dictionary. Each entry in the dictionary is assigned a unique system ID value; this allows the dictionary to store the objects name, user assigned label, date and time updated, and location within the DOS disk structure, in one central place assessable by all

components of the system. The system ID serves as a relational key replicated in all other tables requiring knowledge of the entry. eliminating a great deal of storage redundancy. In summary. the unique system ID assigned to each data object in the dictionary provides two benefits:

- o The system ID for data objects collectively function as MAYA's nervous system, linking the data dictionary (the brain), with the analysis engines (the limbs doing the work), and the user interface (the senses).
- o The system ID for data objects shields system complexity from the user, allowing the user to reference all dictionary objects via user-assigned text labels. Users of MAYA need never directly concern themselves with system IDs when performing all routine operations.

By SQL standards, MAYA's data dictionary is a simplistic one. It comprises only two indexed tables: a table level dictionary and a field level dictionary. The table dictionary contains one record (instance) for each entry known to the system. Note that dictionary *entries* may or may not be database tables. The field level dictionary contains one record (instance) for each database field for each entry that is a database table. Storing table record structures (e.g. field characteristics) this way allows the system to easily replicate any data table required.

MAYA's Menu Subsystem

The menu subsystem employs the horizontal light bar menu (with pull down sub-menus for lower level operations) now familiar to many microcomputer users. Menu options are highlighted in reverse video, and selected using either the first letter of the option, or using the PC keyboards arrow keys. The ESCAPE key is used to move logically backwards at any point in the system. A complete menu hierarchy diagram for MAYA appears in Appendix B.

Additional characteristics of the MAYA Menu Executive include:

- o Pop-up context sensitive help subsystem, accessible anywhere from within the system.
- o A task logging subsystem that stores the description, time and date each task was executed in a database table for perusal at any later time.
- o A "user assigned program list" facility. allowing the user to maintain a list of personal programs for execution within MAYA from a standard menu.
- o A flexible DOS batch execution facility. allowing an arbitrarily long list of DOS tasks to be named and executed as a set of jobs. The list can be seeded from an existing log of previously executed tasks, from any ASCII text file, or interactively from within MAYA.
- o A complete data archive facility that allows vector coverages to be imported, exported, further compressed (via PKZIP/PKUNZIP or ARC), and then backed up (via a backup program such as Fastback Plus or PC Fullbak). Raster maps and other database tables may also be compressed and backed up using the same menu options.

Raster Map Management

When each raster map is created from its vector form cousin, its unique system ID and general characteristics are stored as a record in a raster characteristics database table (MAYARDEF.DBF). Such characteristics include the maps system ID, its cell size, origin and extent in map projection units, and the ID of the vector coverage from which it was generated. The raster map system ID in this record links all raster map characteristics to the actual raster file and location on the DOS disk stored in the data dictionary. Analysis engines requiring the characteristics of a given raster map then use the map's unique ID to key into both the raster characteristics table and the data dictionary. Storing all such map characteristics in a single table this way also provides an easy way to set up a batch job to rasterize a large set of maps at one time.

Input Parameters for Analysis Runs

Input parameters for each analysis run follow a similar procedure. The input parameters are interactively entered by the user within a data entry screen within MAYA, then saved to a record in the MAYAPARM.DBF database table. When the given analysis engine is run, it looks for the inputs selected by the user from a scrollable pick list in the MAYAPARM.DBF table.

Although this method is useful for executing one analysis run at a time, it really becomes advantageous when building larger batch jobs in a production environment. When performing sensitivity analysis, for example, a series of input parameter sets differing by a some constant can be easily set up and defined as a single batch job. At any later point, this analysis batch job may be selected for execution. When the inputs from another batch job needs to be developed, the old parameter sets may be used as seeds, reducing the entry of repetitive inputs common to the old and new jobs.

Feature-Attribute Files for MAYA Analyses

User defined feature-attribute tables provide meaningful associations between features on maps and real world classifications. The point, arc, or polygon attribute tables built within PC ARC/INFO when coverage topology is developed initially include two fields, called COVER#, and USER-ID. The cover number field is a sequential integer value PC ARC/INFO assigns based on the features ordinal position in the list of features for a given coverage. The User-ID field receives the user assigned attribute value (e.g. the LABEL) for the coverage, but is limited to -32767 to 32767 when intended for transfer to a raster map. To overcome this limitation, the COVER# (feature ID) field is typically used as the parity values transferred to raster cells for MAYA maps. An external dBASE III+ database table defined by the user is used to associate each feature ID with a more meaningful attribute code.

Basic Spatial Ingredients For Analyzing Wildlife Habitat Using MAYA

Each MAYA raster analysis requires two types of spatial objects: a background coverage, and a foreground coverage, conceptually overlaid upon the background. The background coverage may consist of either a polygon coverage or a linear (arc) coverage. The foreground coverage is a point coverage, representing a network of discrete animal locations associated with one or more animals observed over a period of time.

MAYA Spatial Analysis Functions

MAYA currently offers four types of spatial analysis functions, performed by custom applications software on raster maps in conjunction with the ad-hoc tools described above. The four analysis functions all perform a point on polygon overlay, and include: a) Point-In-Polygon Identification, b) Point-To-Edge Minimum Distance Analysis, c) Sample Frame Frequency Analysis, and d) Roving Window Simulation Analysis.

Point-In-Polygon Identification

The Point-In-Polygon Identification (abbreviated PIP) analysis overlays a foreground (point) map over a polygon (or line) raster map and returns the background cell attribute underlying each foreground map cell. These results are placed in a dBASE III+ table which may then be viewed or printed from within MAYA.

In a wildlife habitat context, each foreground map (point) represents an animals location at one point in time. Note that the feature ID for each such point does not uniquely identify a particular animal, but instead refers to one animal location among many. The animal occupying a particular location (e.g. feature ID) is determined by virtue of the external feature-attribute table which links individual animals with locations.

At a minimum, then, the feature-attribute record must contain the feature ID field (an integer field usually named FEAT_ID, 5 digits wide). It typically also contains an attribute field (often named ATTR, a character code up to 5 characters wide), which identifies the animal at that location. In addition to these fields, the feature-attribute record may contain any additional fields that further describe characteristics of the point (such as the elevation, aspect, basal area, etc).

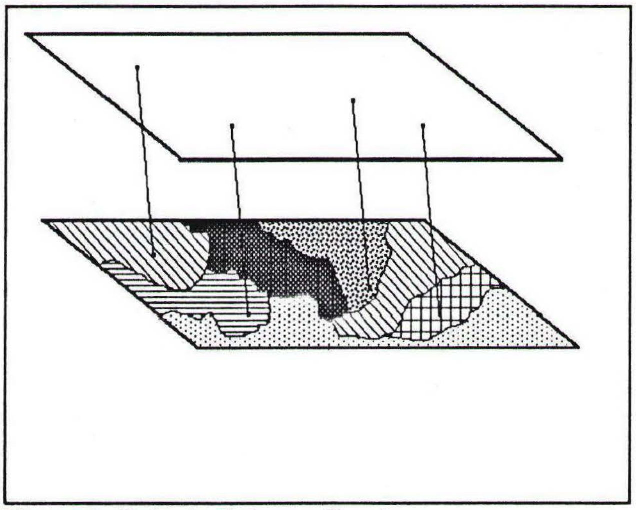


Figure 1 Point-In-Polygon Overlay

The point-in-polygon analysis functions largely in a descriptive role, particularly useful for identifying the underlying classification attribute for a set of animal locations. If a home range map is available for the set of locations, various levels of home range usage could then be associated with vegetation types. If the background polygon was classified into polygons represented by plot samples, then the animal locations could then be matched to one or more sample plot characteristics.

Point-To-Edge Distance Analysis

The point-to-edge distance analysis (abbreviated PTE) calculates the minimum distance, in decimal map units, from one or more points (e.g. animal locations) to the nearest change in background coverage attribute relative to each point. The criteria for the type of change triggering the distance measurement defaults to *any* change in background coverage attribute, given that the attribute directly beneath the point is different than the opposing "edge" attribute. As an alternative to the default, MAYA allows the user to specify that the minimum distance be measured from the point to one or more *specific attributes*, contained in a database table made available to the analysis engine at runtime.

One application for this type of analysis might be the following. A wildlife researcher mapping grizzly bear habitat could identify several vegetation types associated with avalanche chutes, and load these into a lookup database table (possessing a single character field, named ATTR of width 5). The Point-

To-Edge Distance Analysis would then be executed against this table, returning a set of distance measurements from the bear location(s) to the nearest of any vegetation type within the "acceptance set" listed in the table.

Figure 2. illustrates the Point-To-Edge minimum distance relationship. The heavy black bar extending from each point in the figure shows the distance from each animal location to the nearest polygon edge meeting the limit criteria (e.g. membership in the set of attributes making up the acceptance set).

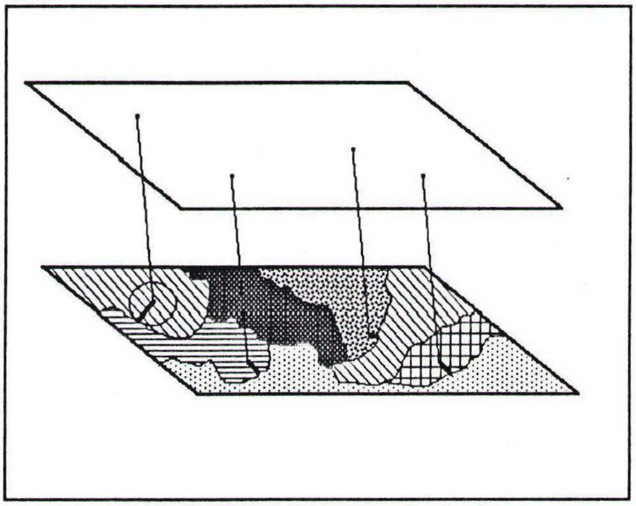


Figure 2 Point-To-Edge Distance Analysis

Sample Frame Frequency Analysis

The sample frame frequency analysis uses foreground raster map points (e.g. animal locations) as the centroids for symmetrically shaped sample frames laid over the background raster map. The sample frame frequency analysis generates a frequency distribution of background coverage attribute codes that lie within one or more of these point-centered sample frames.

The sample frames exist as convex figures whose centroid is defined by each point in the foreground raster coverage. Sample frame shapes are defined as either rectangular or ellipsoidal figures. Square and circular sample frames are simple extensions of the rectangular and ellipsoidal shape classes, and are specified by setting the major and minor sample frame axis lengths equal, respectively. In addition, when ellipsoidal frames are selected, these may be oriented from 1 to 180 degrees, relative to true north, allowing a full 360 degree rotation coverage due to the symmetry of ellipsoids.

Figure 3 illustrates the Sample Frame Analysis map relationship. The frequency distributions returned are expressed as absolute, relative and cumulative frequencies of the mapped attributes within the areas bounded by the sample frame regions. In addition to their use as simple descriptive frequencies, these statistics may be used to build synthetic classes integrated from different habitat factor measures associated with the underlying polygons.

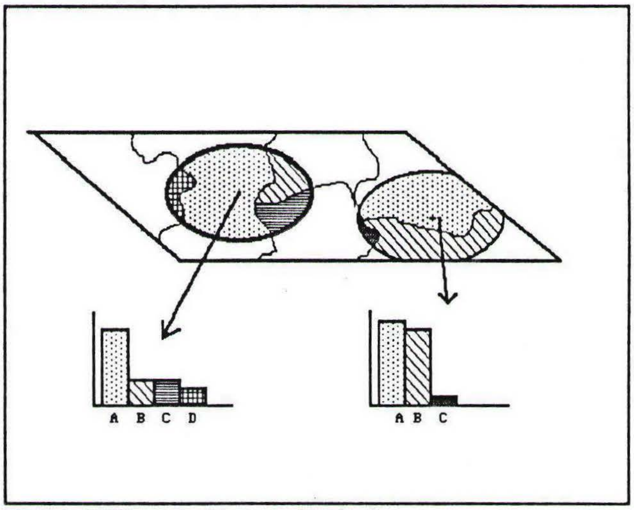


Figure 3 Sample Frame Analysis

As an alternative to the frame based frequency distribution output, the MAYA allows the user to request a simple random point sample, using the sample frame as the bounding region within which a specified number of (background) raster cells are selected. The resulting table then contains the attribute of each background cell randomly selected as well as the foreground (frame center) cell attribute.

Roving Window Simulation Analysis

The roving window simulation analysis is similar to the sample frame frequency analysis, except that the projected sample frames are centered about points placed according to randomization parameters specified by the user. These parameters include the number of random points (e.g. simulated sample

frames), the point distribution method, the shape and orientation of the frames, and the analysis method to use within each frame.

The simulated sample frames may be laid out in one of three ways: a) in regular strip patterns, starting at the north-west corner of the map and stepping across from west to east, repeating this pattern from north to south, b) in a uniformly random pattern relative to the entire raster map, and c) in a gaussian distributed random pattern. If the gaussian random placement method is used, the shape of this pattern is governed by a user specified mean north-south and east-west coordinate (and corresponding north-south and east-west standard deviation).

Location of the sample frames is done *with replacement*, so that the placement of the frames represent independent trials whose boundaries may or may not overlap, depending on the sample density requested. Sample frames whose boundaries extend beyond the edge of the maps are automatically clipped at the edges.

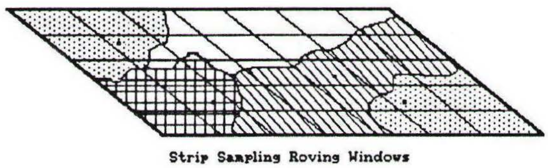


Figure 4 Roving Window Simulation Analysis

Within the sample frames, one of two sampling functions may be specified. An attribute based frequency distribution may be generated, identical to the one offered within the sample frame analysis described above, or a random point sample within the frame may be drawn. The random point sample method returns the background cell attribute for each point within the frame randomly selected with replacement. An intensity parameter (a value between 0.0 and 1.0) specified by the user governs the percentage of within-frame cells sampled.

Figure 4 illustrates the roving window simulation, using the regular strip sampling method. For each of the large rectangular frames, a frequency distribution of underlying polygon attributes is generated.

Several of these habitat analysis functions may also be performed using their vector form equivalents, in a piecemeal rather than batch fashion, using PC ARC/INFO interactively. For example, the point-in-polygon analysis is easily accomplished using the ARC/INFO overlay module IDENTITY command. The sample frame analysis may be performed by building a CLIP coverage using GENERATE, and then performing an overlay using the IDENTITY function. The advantages of using MAYA's raster spatial functions (rather than PC ARC/INFO alone) for these four tasks is that:

- o MAYA's analysis functions each produce a standardized database result table, from which formatted output reports may produced.

- o A arbitrary number of input parameter records for a given type of analysis may be defined beforehand, stored, and then executed as a batch. This capability extends to all four types of analyses, so that six of one type, four of another, and five of a third type could all be included within one batch analysis job.

- o In the case of the Point-To-Edge Distance Analysis, no straightforward method using PC ARC/INFO exists to obtain these results. Although it is straightforward to visually overlay a point over a polygon coverage, and then interactively obtain the distance between any two points using the MEASURE command, it is quite difficult to ascertain if the endpoints chosen represent the real minimum distance on a complex polygon coverage.

A Case History: S. Fork Flathead Grizzly Habitat Study Area

A 46,000 hectare study area in the South Fork Flathead River drainage was chosen as a pilot area to evaluate the MAYA analysis functions. This study area was originally delineated by Hadden (1987) within the context of a study to further develop and test the habitat assessment techniques of Hadden (1986) using a historical set of grizzly bear radio locations. Their approach employed a hierarchical habitat classification of vegetation types at various succession stages. A total of 51 community types were eventually identified from an analysis of 1449 stand point samples.

Complete evaluation results for this study area are not available at the time of this writing. A smaller subset region consisting of the approximately the upper third of the study area was developed, against which the Point-In-Polygon and Point-To-Edge Distance analysis were tested.

Point In Polygon Analysis: Pilot Test Results

Background Polygon Map: Raster Coverage SFTEST

The background polygon map was derived from a of the study area consisted of 608 polygon features, a subset of some 1391 polygons delineated in the original South Fork study area. Each of the polygons were matched to one of the 1449 sample plots. The data items collected for each sample plot are listed in Appendix C.

Foreground Point Map: Raster Coverage BEARRAST

The foreground point map was developed using 89 grizzly bear locations obtained from Mace (1988) that fell within the above pilot test area. The data items comprising each point location record are listed in Appendix D. A subset of these fields were extracted to build the actual foreground point coverage, using the GENERATE facility within PC ARC/INFO. The extracted fields included BEAR, LOCNUM, UTMX and UTMY.

The result table generated by the Point-In-Polygon Analysis has the following structure:

```
Structure for database : PIP1RSLT.DBF

Field  Field Name  Type       Width  Dec   Usage
    1  PT_FEAT_ID  Number        5.    0   Animal Location No.
    2  PT_ATTR     Character     5.    0   Bear ID Code
    3  PT_BKATTR   Character     5.    0   Background attribute At Location
    4  BK_FEAT_ID  Number        5.    0   Background map polygon number
```

The selected contents of the Point-in-Polygon result table are shown below. The full result table appears in Appendix E. This table contains one record for each discrete animal location, and includes the point's feature ID (referring to the location), the point's attribute (referring to the particular animal at the location), and the background cells feature ID and attribute code.

PT_FEAT_ID (Location#)	PT_ATTR (BearID)	PT_BKATTR	BK_FEAT_ID
81	144	-99	0
93	146	20	1248
46	4	32	1244
92	146	31	1118
94	150	42	1002
.....			
.....			
1	1	-99	0
15	4	-99	0

Point-To-Edge Distance Analysis: Pilot Test Results

The result table produced by the Point-To-Edge analysis is similar to the one produced by the point-in-polygon analysis, with the addition of the MIN_DIST field, which contains the distance in map units from the location point to the nearest change in background attribute. The BK_ATTR field contains the user defined attribute -- in this case, the vegetation type code from 1..52 associated with the background map cell terminating the distance measure. Selected records from the point-to-edge distance analysis are shown below. The full result table appears in Appendix E.

PT_FEAT_ID	PT_ATTR	PT_BK_ATTR	BK_FEAT_ID	BK_ATTR	MIN_DIST
81	144	-99	1256	45	111.8
93	146	20	1002	42	50.0
46	4	32	1009	22	50.0
92	146	31	1191	39	50.0
94	150	42	950	49	538.5
......					
83	146	-99	1002	42	2491.0
53	143	-99	900	39	600.0

Sample Frame and Roving Window Simulation Result Table

The sample frame analysis and roving window simulation analysis both produce tables that list for each sample frame the frequency distribution of background map attributes within the frame. The structure of these database tables is shown below:

Field	Field Name	Type	Width	Dec	Description
1	FRAME_ID	Number	5.	0	: Sample Frame No.
2	FORE_ATTR	Character	5.	0	: Origin cell attribute
3	CELL_ROW	Number	4.	0	: Origin cell row
4	CELL_COL	Number	4.	0	: Origin cell column
5	BACK_ATTR	Character	5.	0	: Background cell attribute

```
    6  ABS_FREQ     Number          8.   0 : Absolute freq. of back attribute
    7  REL_FREQ     Number          5.   1 : Relative freq. of back attribute
    8  CUM_FREQ     Number          5.   1 : Cumulative freq. of back attribute
    9  FRAMESIZE    Number          9.   1 : Frames size in square map units.
** Total **                        51
```

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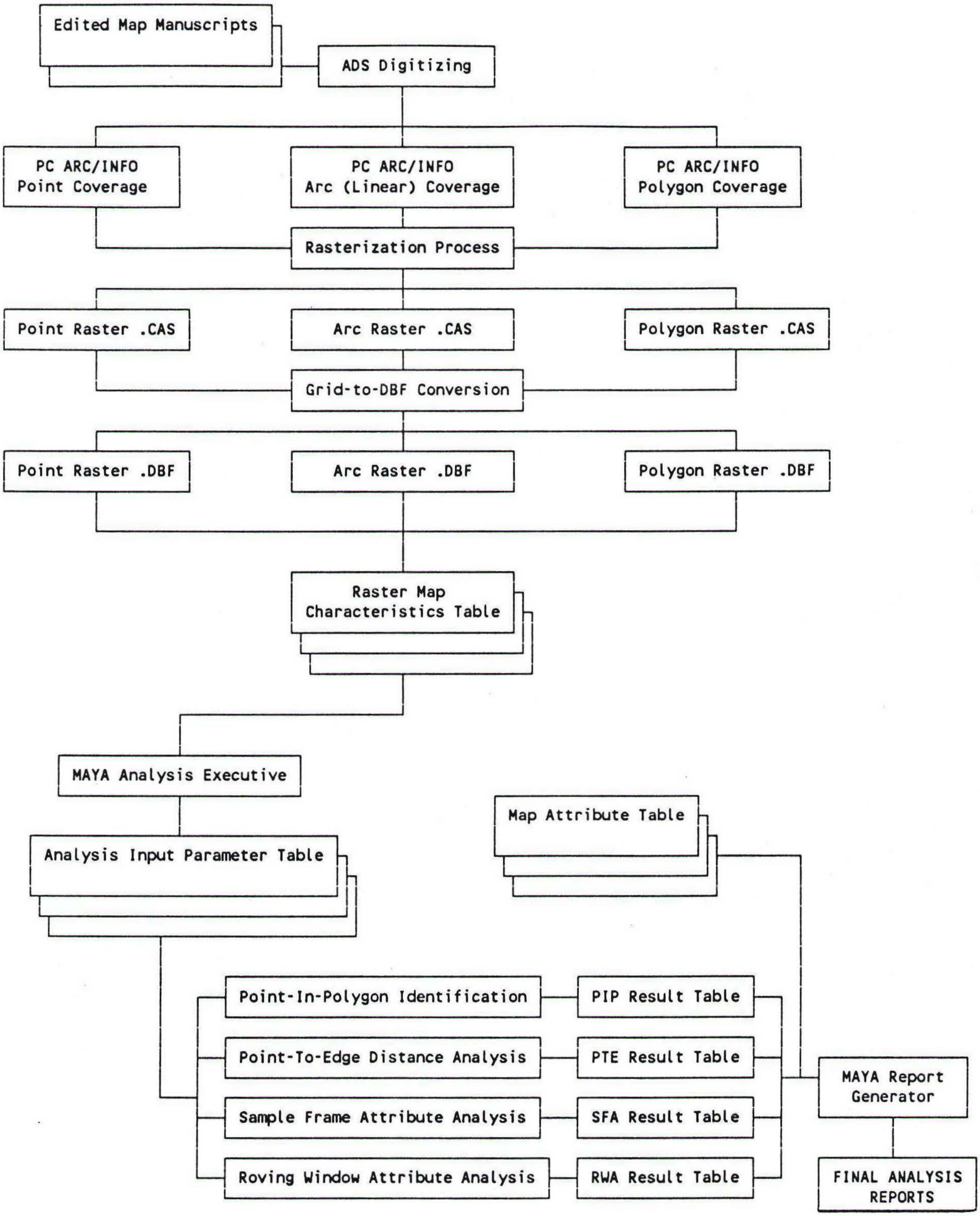
Appendix A: MAYA Data and Process Flow Diagram



Appendix B: MAYA's Hierarchical Menu Structure

DATA

DOS DIRECTORY LIST

CONVERT DATA SERVICES
- MAYA DBF To INFO Table
- INFO Table To MAYA DBF
- Raster Grid to DBF or Text

LIST COVERAGES

ARCHIVE SERVICES
- IMPORT a PC ARC/INFO Coverage
- EXPORT a PC ARC/INFO Coverage
- Archive (Squeeze) A Set of Files
- Restore Set of Archived Files
- View Directory of File Set Within Archive
- Backup Files To Backup Media

TELECOMMUNICATIONS SERVICES

MAINTAIN DATA TABLES
- View DBF Table Structure
- Append ASCII Data To Database Table
- Replace Data Table Field Values
- Delete Data Records Selectively
- Modify A Data Table Structure
- Erase A DBF, INFO Table or Vector Coverage

EDIT-VIEW

DBF TABLE EDIT-VIEW
- Select
- View
- Edit
- Create
  - Select A Pre-Defined Table Name
  - Introduce An Existing Attribute Table
  - Create A User-Defined Table Type
  - Create New Table Now

TEXT FILE EDIT-VIEW
- Select
- View
- Edit
- Create

GIS SERVICES

PC ARC/INFO COMMAND ACCESS

DESCRIBE COVERAGE
- Type of Coverage
- Enter Coverage Name
- Report Destination
- Begin Description Now

RASTERIZATION SERVICES
- Select An Existing Raster Map Definition
- Create New Raster Map Definition
- Edit Selected Raster Map Definition
- Delete Selected Raster Map Definition
- Begin Rasterization Now

	GENERATE COVERAGE		
		New Coverage Name	
		Command File for Generate Job	
		Run Generate Now	
	QUICK PLOT VIEW		
ANALYSIS SERVICES	MAYA RASTER ANALYSIS FUNCTIONS		
		MAYA Raster Analysis Startup Services	
			Choose An Analysis Input Parameter Set
			View-Edit Selected Analysis Input Parameter Set
			Delete Selected Analysis Input Parameter Set
			Run Selected Analysis Now
		Identify Point-In-Polygon Analysis	
		Point-To-Edge Distance Analysis	
		Sample Frame Analysis	
		Roving Window Simulation Analysis	
	ANALYSIS BATCH JOB SERVICES		
		Enable/Disable Analysis Input Sets	
		Delete All Disabled Analysis Input Sets	
		Run ALL Enabled Analysis Input Sets	
	DOS BATCH JOB SERVICES		
		Select An Existing Batch Job	
		Create A New Batch Job	
		Empty Out All Batch Jobs	
	RUN A USER-ASSIGNED PROGRAM		
REPORTS	DATABASE TABLE PRINT		
	TEXT FILE PRINT		
	MOST RECENT REPORT		
	BEGIN PRINTING REPORT		
SYSTEM	LOG SYSTEM ACCESS		
	DATA DICTIONARY SERVICES		
		View (Passively) Data Dictionary	
		Add-Edit Data Dictionary	
		Produce A Dictionary Report	
		Restore Dictionary Integrity	
	EDIT USER PROGRAM LIST		
	CONFIGURE DEFAULTS		
	SYSTEM STATUS		
	RUN ANY DOS COMMAND		
QUIT	Enter (Q) Quit To DOS or (C) Cancel And Return to MAYA		

Appendix C: South Fork Study Plot Items

Structure for database : SFBEAR.DBF
Date of last update : 04/13/88 (Vers. 3)

Field	Field Name	Type	Width	Dec
1	OBS	Number	1.0	
2	PLOT	Number	3.0	
3	BSPP	Number	1.0	
4	SCON	Number	1.0	
5	USE	Number	1.0	
6	UCON	Number	1.0	
7	JDATE	Number	3.0	
8	DCON	Number	1.0	
9	FOOD	Number	4.0	
10	PHEN	Number	1.0	
11	PART	Number	1.0	
12	WILD	Number	1.0	

Structure for database : SFDESC.DBF
Date of last update : 04/13/88 (Vers. 3)

Field	Field Name	Type	Width	Dec
1	OBS	Number	1.0	
2	PLOT	Number	3.0	
3	JUL	Number	3.0	
4	DAY	Number	2.0	
5	MON	Number	2.0	
6	YEAR	Number	2.0	
7	STAND	Number	11.0	
8	ET	Character	1.0	
9	VT	Character	4.0	
10	VTC	Character	1.0	
11	DOM	Number	8.0	
12	SC	Number	1.0	
13	LAT	Number	7.0	
14	LONG	Number	6.0	
15	ACC	Number	1.0	
16	ELEV	Number	4.0	
17	ASP	Number	4.0	
18	SL	Number	2.0	
19	POS	Number	1.0	

Structure for database : SFHIST.DBF
Number of data records : 1446
Date of last update : 04/13/88 (Vers. 3)

Field	Field Name	Type	Width	Dec
1	SEQ	Number	4.0	
2	OBS	Number	1.0	
3	PLOT	Number	3.0	
4	SOIL	Number	2.0	
5	ROCK	Number	2.0	

Structure for database : SFHIST.DBF (continued)

Field	Field Name	Type	Width	Dec
6	MOSS	Number	2.0	
7	WDL	Number	2.0	
8	ATH	Number	3.0	
9	TTC	Character	1.0	
10	POLE	Character	1.0	
11	SAPL	Character	1.0	
12	SEED	Character	1.0	
13	TSC	Character	1.0	
14	TALLC	Character	1.0	
15	MIDC	Character	1.0	
16	GRAM	Character	1.0	
17	FORB	Character	1.0	
18	PDIS	Number	2.0	
19	PINT	Number	4.0	
20	SDIS	Number	2.0	
21	SINT	Number	1.0	
22	SYEAR	Number	4.0	

Appendix D: Grizzly Bear Location Database Items

Structure for database : INCORE.DBF
Date of last update : 03/09/89 (Vers. 3)

Field	Field Name	Type	Width	Dec
1	BEAR	Number	3.	0
2	SEX	Character	2.	0
3	LOCNUM	Number	3.	0
4	DATE	Date	8.	0
5	JULEDATE	Number	3.	0
6	TIME	Number	4.	0
7	DRAIN	Character	4.	0
8	QUAD	Character	2.	0
9	VISUAL	Character	1.	0
10	INHABCORE	Character	1.	0
11	INPOPCORE	Character	1.	0
12	LOCTYPE	Character	1.	0
13	LOCQUAL	Character	2.	0
14	LOCUSE	Character	2.	0
15	WEATHER	Character	1.	0
16	ACTIVITY	Character	1.	0
17	ACTSHIFT	Number	2.	0
18	DENNED	Character	1.	0
19	ELEV	Number	4.	0
20	ASP	Number	3.	0
21	SLOPE	Number	2.	0
22	POSITION	Character	2.	0
23	CT	Character	2.	0
24	FEATURE	Character	2.	0
25	SITE	Character	2.	0
26	MOIST	Character	2.	0
27	HABTYPE	Character	6.	0
28	ROADDIST	Number	4.	0
29	ROADTYPE	Character	2.	0
30	OPEN	Character	1.	0
31	UTMZONE	Number	2.	0
32	UTMX	Number	6.	2
33	UTMY	Number	7.	2
34	APOLYX	Number	6.	2
35	APOLYY	Number	7.	2
36	BPOLYX	Number	6.	2
37	BPOLYY	Number	7.	2
38	CPOLYX	Number	6.	2
39	CPOLYY	Number	7.	2
40	DPOLYX	Number	6.	2
41	DPOLYY	Number	7.	2
42	EPOLYX	Number	6.	2
43	EPOLYY	Number	7.	2
** Total **			155	

Appendix E: Point-In-Polygon and Point-to-Edge Distance Result Tables

Point-In-Polygon Result Table Example

PT_FEAT_ID (Location#)	PT_ATTR (BearID)	PT_BKATTR	BK_FEAT_ID	BK_ATTR
81	144	-99	0	-99
93	146	20	1248	20
46	4	32	1244	32
92	146	31	1118	31
94	150	42	1002	42
80	144	44	1012	44
52	97	49	1010	49
45	4	42	1005	42
43	4	25	1014	25
44	4	-99	0	-99
42	4	42	1005	42
40	4	42	1002	42
41	4	-99	0	-99
51	97	46	1021	46
39	4	-99	0	-99
91	146	49	950	49
38	4	46	1021	46
76	143	47	1020	47
50	97	49	829	49
35	4	22	1348	22
36	4	-99	0	-99
37	4	-99	0	-99
34	4	42	1002	42
79	144	-99	0	-99
33	4	-99	0	-99
75	143	49	950	49
32	4	49	950	49
31	4	46	735	46
30	4	48	996	48
90	146	42	824	42
27	4	16	756	16
89	146	-99	0	-99
25	4	-99	0	-99
74	143	-99	0	-99
23	4	15	769	15
24	4	19	765	19
21	4	5	755	5
88	146	-99	0	-99
22	4	-99	0	-99
49	97	-99	0	-99
73	143	49	950	49
19	4	49	1000	49
20	4	49	1000	49
18	4	46	1006	46
17	4	14	750	14
87	146	43	774	43
16	4	-99	0	-99
72	143	-99	0	-99
1	1	-99	0	-99
15	4	-99	0	-99

PT_FEAT_ID	PT_ATTR	PT_BK_ATTR	BK_FEAT_ID	BK_ATTR	MIN_DIST
41	4	-99	1005	42	461.0
51	97	46	950	49	50.0
39	4	-99	1005	42	531.5
91	146	49	1002	42	50.0
38	4	46	825	47	50.0
76	143	47	1054	-99	50.0
50	97	49	824	42	250.0
35	4	22	1002	42	70.7
36	4	-99	1329	19	353.6
37	4	-99	1329	19	495.0
34	4	42	950	49	50.0
79	144	-99	1002	42	158.1
33	4	-99	1329	19	206.2
75	143	49	739	50	291.5
32	4	49	1002	42	100.0
31	4	46	802	-99	50.0
30	4	48	950	49	50.0
90	146	42	832	40	50.0
27	4	16	745	-99	50.0
89	146	-99	1002	42	223.6
25	4	-99	1330	35	585.2
74	143	-99	1002	42	158.1
23	4	15	765	19	50.0
24	4	19	745	-99	50.0
21	4	5	809	43	50.0
88	146	-99	1002	42	50.0
22	4	-99	1002	42	626.5
49	97	-99	829	49	111.8
73	143	49	931	25	100.0
19	4	49	903	45	111.8
20	4	49	903	45	100.0
18	4	46	950	49	50.0
17	4	14	756	16	50.0
87	146	43	794	47	50.0
16	4	-99	1002	42	427.2
72	143	-99	1002	42	538.5
1	1	-99	1002	42	509.9
15	4	-99	1002	42	50.0
14	4	46	950	49	111.8
71	143	-99	1002	42	380.8
13	4	-99	1002	42	111.8
86	146	42	0	-99	100.0
78	144	-99	934	44	531.5
12	4	42	0	-99	111.8
11	4	42	751	19	50.0
85	146	-99	934	44	353.6
10	4	-99	934	44	531.5
9	4	19	934	44	50.0
70	143	-99	934	44	461.0
69	143	-99	934	44	291.5
68	143	-99	934	44	360.6
8	4	-99	1002	42	471.7
67	143	-99	934	44	559.0
7	4	-99	1002	42	150.0
66	143	49	943	11	50.0

PT_FEAT_ID	PT_ATTR	PT_BK_ATTR	BK_FEAT_ID	BK_ATTR	MIN_DIST
6	4	-99	1330	35	1 700.0
84	146	49	1356	52	70.7
64	143	39	821	20	50.0
48	97	46	910	48	100.0
5	4	20	785	39	70.7
63	143	42	914	41	70.7
4	4	20	785	39	70.7
62	143	46	945	47	50.0
47	97	48	937	46	141.4
77	144	39	820	20	70.7
59	143	46	909	21	50.0
61	143	48	907	46	50.0
60	143	-99	880	42	100.0
57	143	39	922	20	70.7
3	4	20	783	39	50.0
56	143	16	949	11	50.0
55	143	39	897	16	50.0
2	4	16	929	45	50.0
54	143	-99	933	28	461.0
82	146	-99	933	28	50.0
83	146	-99	1002	42	2491.0
53	143	-99	900	39	600.0

MESSAGE DISPLAY

TO: D.Thompson:S22A

From: L. Jack Lyon:S22L01A
Postmark: Jun 09,89 11:14 AM
Status: Previously read
Subject: Reply to: SYSTEMS FOR ENVIROMENTAL MGT COOP AGREEMENT #INT-87215

Reply text:
From L. Jack Lyon:
Sorry about that. I thought I sent a letter in December saying that we have several kinds of interim reports, but that I didn't want to file any of them as the final on this agreement.
New thought. Joe Glassy and I just did a paper for a GIS conference in Wenatchee. I'll send a copy as the final report for this agreement. is it really?

Preceding message:
From Beatrice Abbato acting for D.Thompson:
We have not received further information on this agreements closure.
What's the status?

---------------X---------------